URSI GASS 2020, Rome, Italy, 29 August - 5 September 2020

Studying the temporal variations of atmosphere physical properties at different spatial and temporal scales by VLF radio signals and space geodesy techniques

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Abstract

In this work we study the physical variations of atmosphere at different spatial and temporal scales. The temporal evolution of the amplitude of Very Low Frequency (VLF) radio signals is used as a means to characterize the seasonal variations of atmosphere. The microwave-based GNSS and Synthetic Aperture radar (SAR) interferometry techniques are used as a means to characterize anomalies in the physical properties of atmosphere due to solar X-ray flares.

1 Introduction

The propagation of radio and microwaves in the atmosphere can help to study the properties of atmosphere at different spatial scales. In this work we focus on two specific frequency ranges: 1) Very Low Frequency (VLF) radio waves and 2) microwaves used by GNSS and spaceborne SAR systems. The first frequency range has an important application in the study of many phenomena including earthquake precursors [1-4], tropical cyclones [5], influence of solar X-ray flares [6], gamma ray bursts [7]. The second frequency range is of interest in space geodesy with applications spanning a large set of examples from geology to GNSS and SAR interferometry (InSAR) meteorology [8-11]. In both cases, meteorological conditions, solar bursts and geomagnetic activity affect propagation of signals. The intensity of solar radiation is main driving factor shaping the spatial and temporal distribution of electron density and daytime/nighttime variations of ionosphere properties. During daytime, the ionosphere is divided in three layers: F, E and D. The electron density is the largest in F-region while it attains a minimal value in the D-region. In the nighttime the lowest layers of ionosphere dissipate their electron density due to decrease of incoming solar radiation and, consequently, have a lower ionization. Significant differences in ionosphere are also observed moving from the equator towards the polar region. These changes are a due to the morphology of the geomagnetic field. As a consequence, the ionosphere can be divided in equatorial, middle-latitude and polar ionosphere. The knowledge of all these variations is important not only to describe the quiet ionosphere but also to study the influences of different geophysical and astrophysical events and processes on local plasma characteristics which can be quasi-permanent, periodical and sudden in time. For example, the influence of X-radiation on D-region perturbation is more important than on the upper ionosphere [12], while entering and penetration of charged particles depend on the geomagnetic field and their influence is the most important at polar region. In this study we describe a methodology to study the lower ionosphere based on the use of VLF waves. The dominant sources of ionization in the D regions are Lyman alpha radiation during quite conditions. We will study this phenomenon using the VLF receivers of the INFREP, a European radio network of several VLF/LF radio receivers which have been installed throughout Europe since 2009 [1-3].

2 Study of VLF propagation in atmosphere

VLF radio signals have a frequency in the bands 20-80 kHz. As a good approximation, we can model the propagation of VLF radio signals as characterized by a ground-wave and a sky-wave propagation mode. The first one generates a radio signal that propagates in the channel ground-troposphere, while the second one generates a signal which propagates using the lower ionosphere as a reflector. Generally, due to the different conditions of the ionosphere, the VLF radio signals are less disturbed during the night than during the day. Figure 1 shows and examples of intensities of VLF signals measured at the INFREP receivers. VLF signals recorded during night can be used to study propagation in the atmosphere quite undisturbed conditions. We use long time-series of VLF signals propagating during night to study possible seasonal effects due to temporal variations in the physical properties of troposphere. A graph theory approach is used to investigate the spatial correlation of the aforementioned effects at different receivers. A multivariate analysis is also applied to identify common temporal changes observed at VLF receivers.

However, also during daytime disturbed VLF signals can provide useful information. During daytime the GOES satellite can be used to measure the temporal evolution of X-ray radiation from sun and so study the corresponding variation of physical properties in the D-region of ionosphere by means of VLF signals.

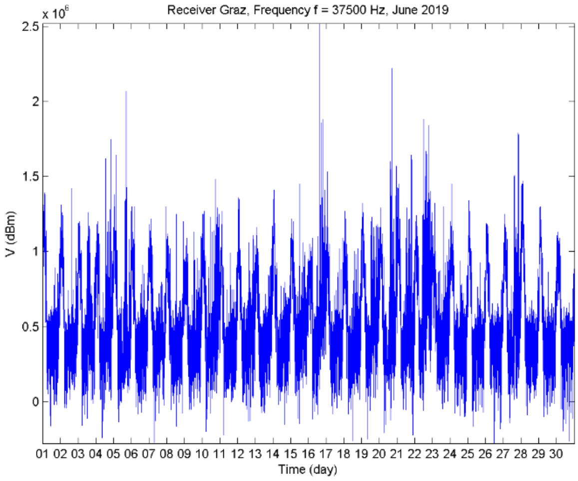

Figure 1. Amplitude of VLF signal vs time. The different behavior during day (lower amplitude) and night (higher amplitude) times can be observed.

3 INFREP network

The INFREP network currently consists of nine receivers located in different countries in southern Europe: two in Romania and Greece, one in Italy, Austria, Portugal, Cyprus and Serbia. The receivers measure the intensity of 10 radio signals in the band VLF (10-50 kHz) and LF (150-300 kHz), using a 1-min sampling rate. The transmitters are standard radio broadcasting (LF) or systems used for radio-navigation, time signal and mainly for military purpose (VLF). Figure 2 display the location of receivers and VLF/LF transmitters. More information about the activity of the INFREP network is available at the URL www.infrep-network.eu where interested users can register, download data and visualize results.

4 Effects of D-region disturbances on space geodesy techniques

The influences of upper ionospheric disturbances on space geodesy technique have been already studied. Here we focus on the influence of D-region disturbances on GNSS and SAR interferometry (InSAR) space geodesy techniques. We focus on this lower part of ionosphere as it can be studied by VLF signals and so it is a good case study for the aim of this paper. The most important influence on the mid latitude D-region coming from the Sun.

Figure 2. INFREP network: current set of the receivers and VLF/LF transmitters overlaid to a Google© map. More information is available at the URL www.infrep-network.eu.

However, effects of photons and charged particles are different. Namely, in addition to Ly-α radiation, increased X radiation during solar X-ray flares significantly disturb this atmospheric part, while ionization of the mid latitude D-region by charged particles is not so important.

Disturbances on GNSS and InSAR signals in the D-region perturbed by solar X-ray flares has been studied, recently [13]. Besides being a problem for these space geodesy techniques as it causes artifacts to be mitigated, it has been proposed to use InSAR images to study this phenomenon at a higher spatial resolution [14].

On the other side, variations in the D-region properties are primary studied at high latitude. In Figure 3 we present time evolutions of NRK and NAA VLF signals emitted in Iceland and the USA and received in Belgrade by the AWESOME (Atmospheric Weather Electromagnetic System for Observation Modeling and Education) receiver on 24 January, 2012 when charged particles rates increase due to a coronal mass ejection. In the three upper panels time evolution of electrons with energies larger than 0.8, 2 and 4 MeV are presented. As one can see, there is not clear similarity in these evolutions. Further work is needed to detect the effects of D-region perturbations in VLF radio signals and image them by means of SAR interferometry.

4 Conclusions

In this work we discussed the use of VLF radio signals, GNSS data and InSAR images as a means to study the temporal evolution of physical properties of atmosphere at different temporal and spatial scales. We focused on the D-region of ionosphere as it is the most affected during X-ray flares, the less modeled in GNSS and InSAR applications and the region where the synergy between VLF, GNSS and InSAR data is the most fruitful.

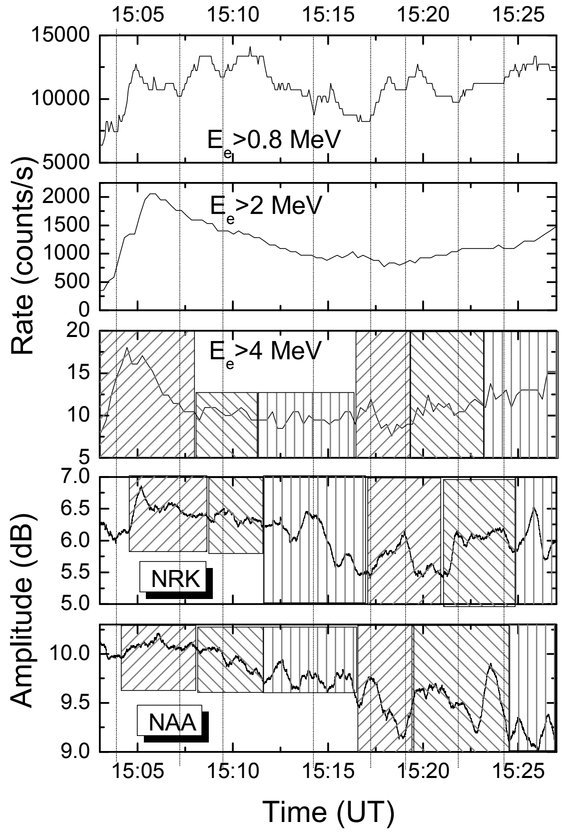

Figure 3. Time evolutions of detection rates of electrons with energies of 0.8, 2 and 4 MeV by the GOES satellite (upper three panels), and amplitudes of NRK and NAA VLF signals emitted in Iceland and the USA and received in Belgrade by the AWESOME receiver (bottom two panels) on 24 January, 2012.

6 Acknowledgements

This work was supported by the Ministero dell'Istruzione, dell'Università e della Ricerca (MIUR), Italy, under the project OT4CLIMA. This research is supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia, under the projects 176002 and III44002.

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